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Determination of Some Selected Engineering Properties of Sweet Potato Cuts as Function of Temperature

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Abstract: Some selected engineering properties of sweet potato as function of temperature (-18 to 33°C) and geometries (slab and cylinder) were studied. Transient heat transfer method was used for the determination of parameters among which is density, specific heat and thermal diffusivity at constant moisture level of 71.7±0.76% (wet basis). Both the density and specific heat of the sample increased with increase in temperature to maximum levels after which further increase led to a reduction of these parameters values and were independent of sample's geometry. The thermal diffusivity and computed thermal conductivity were found to increase with increase in temperature. Conclusively, these engineering properties were correlated with temperature using polynomials of the third order empirical equation.

Key words: Engineering properties, density, specific heat, thermal conductivity thermal diffusivity and sweet potato

INTRODUCTION

Sweet potato (*Ipomea batatas*) is believed to have originated in South America, Polynesia and New Zealand. It is an important food for both children and adult in a variety of forms such as alone, supplemented with protein staples, or in the preparation of other high quality food products using sophisticated method of curing and storage under controlled conditions. Reduction in the amount of time and labour necessary for preparation of sweet potato dishes would enhance its consumption and thus the intake of its nutrients (Horton,1988).

There has for some years been widespread interest in the engineering or physical properties of foodstuffs, fresh or processed. Food researchers require the information for various purposes such as process design, quality assessment and evaluation, etc. Knowledge of these engineering properties of foodstuffs such as density, specific heat, thermal conductivity and thermal diffusivity is necessary not only because they are important on their own right but also because they are the commonest indicators of other properties and qualities.

These engineering properties are known to be affected by density, moisture content and temperature. Thermal conductivity of most foods increased with an increase in moisture content and density (Wallapapan and Sweat, 1982). Specific heat of defatted soyflour increased linearly with moisture content while that of grain dust also increased almost linearly (Chang *et al.*, 1980; Wallapapan *et al.*, 1984). Bulk density of food grains (sorghum, millet and rapeseed) decreased with increase in moisture content up to 30% (Kukelko *et al.*, 1987; Visvanathan *et al.*,1990).

A review of pertinent literature revealed that such data on tropical crops like sweet potato is lacking, hence the objective of this study was to investigate the effect of temperature on the engineering properties of sweet potato. The temperature ranges investigated include ambient values and values below freezing point of the food sample. This invariably gives a wider application of these engineering data.

MATERIALS AND METHODS

Materials: The sweet potato (*Ipomea batatas*) used for this study was purchased from Kuto-a local market in Abeokuta, Ogun state, Nigeria. The sample was prepared by peeling, washing and slicing to two different geometrical shapes (slab and cylindrical) The Slab (or block) measured 3 cm length x 2 cm width x 1 cm thickness while the cylinders are of 3 cm length x 1 cm diameter. The average initial Moisture Content (M.C) of the sample was determined to be 71.7±0.76% using A.O.A.C (1984) technique.

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Experimental procedure

Solid density (ρ) measurement: Equal mass (5.0 g) of the sample was weighed and put into 100 mL measuring cylinder containing 50 mL water (as floatation liquid) using simple floatation principles (Nwanekezi and Ukagu, 1999). The difference in volume was noted and was equal to the volume occupied by the 5.0g sample. The density was derived from the mass of sample divided by volume occupied.

$$\rho = \frac{\text{Mass of sample (kg)}}{\text{Volume occupied by the sample (m}^3\text{)}} \qquad (1)$$

Specific heat (CP) measurement: About 100 g of heated water were weighed into the inner cylinder of a lagged copper calorimeter. When the temperature of the water and cylinder had equilibrated to the required temperature of 50°C, a 5.0 g sample was placed in the cylinder and then covered. The cylinder content was stirred at 2 min intervals using a copper stirrer and the temperature of the water was monitored at regular interval for 1 h (Mohsenin, 1980). The Eq. 2 was used to evaluate the value for the specific heat of the sweet potato sample.

$$C_p = \; 1/M_p \; [M_w C_w G_w/G_p - M_c C_c]/60 \qquad (2)$$

where, M_p, M_w and M_c are the masses of sample, water and calorimeter, respectively; C_w and C_c are the specific heat capacity of water and calorimeter, respectively; G_w and G_p are the slope of cooling curve for water and sample respectively (McProndand Lund, 1983).

Thermal diffusivity (α) measurement: The thermal diffusivity of the sample at constant moisture content was determined by the method of Tong *et al.* (1993). The probe was connected by K-thermocouple wires to an Alda AVD 890C$^+$ digital multimeter. The temperature history of each sample was determined by insertion of the probe into the centre, that is, at the radial axis of the sample. The sample packaged in polythene was placed in a water bath at constant temperature of 50°C and the temperature history was recorded at 10 sec intervals for about 5 min.

At Fourier 0.1, the solutions to the heat transfer equation for an infinite geometry using Eq. 3 and 4 is as follows:

$$\text{In}\left(\frac{T_s - T}{(T_s - T_i)}\right) = \text{Cons tan t} - \frac{(5.783\alpha)}{r^2} \qquad (3)$$

where, T_s is the medium temperature (°C); T_i is the initial temperature of the sample (°C), T is the temperature of the sample at time, t (°C), r is the radius or half the thickness of the sample (Carslaw and Jaegar, 1959).

The thermal diffusivity was then calculated from the slope of a plot of the natural logarithm of the unaccomplished temperature Vs time.

Statistical analysis: The engineering data obtained were subjected to analysis of variance (ANOVA) to give a suitable correlation in order to explain the variation of the engineering properties against temperature by evaluating the coefficient of determination (R^2) and Standard Error (S.E)

RESULTS AND DISCUSSION

Solid density: The density of the sample were determined as a function of temperature in the range of -18 to 33°C sand presented in Table 1. It was observed that the density of the sample increased with increase in temperature up to 5°C after which a subsequent increase in temperature led to decrease in density because of the anomalous behaviour of water in the frozen state. The magnitude of change in density was proportional to the moisture content of the product as reported by Singh and Heldman (1993). The plot of the densities of the sample against temperature gave a curvilinear relationship between the two variables as shown in Fig. 1a and an empirical equation was considered:

$$\rho_{s.\,potato} = 1218.036 + 4.611T - 0.028T^2 - 0.003T^3 \qquad (4)$$
$$(R^2 = 0.96;\;\; S.E=12.02)$$

Specific heat: Using the data obtained for heat loss of the frozen and unfrozen sweet potato at initial water temperature of 50°C, the mean experimental values is as shown in Table 1 at temperature range of-18 to 33°C. The specific heat of the sweet potato used in this study ranged from 1254 to 2768 J kg^{-1} °C for the various temperatures. The specific heat increases with increase in temperature up to a peak (freezing state) and then decreases (heating state) with further increase in temperature. This corroborates the results reported by Taiwo *et al.* (1995). However, the method used was independent of geometries (McProndand Lund, 1983). Changing state of the ice, i.e., freezing front influences the specific heat at a critical temperature of -10°C in the sample. Below-10°C, there was a sharp drop for the sample as shown in the Table 1 while subsequent value increased with further increase in temperature. This further affected the thermal diffusivity and thermal conductivity especially that of cylindrical geometry of the sample.

Table 1: Measured and computed engineering properties of sweet potato at different temperatures

T(⁰C)	ρ (kg m^{-3})	Cp (kJ kg^{-1} °C)	α_{slab}x10^{-8} (m^2 s^{-1})	$\alpha_{cylinder}$x10^{-8} (m^2 s^{-1})	λ_{slab} (W mK^{-1})	$\lambda_{cylinder}$(W mK^{-1})
-18	1149.43±0.764[a]	1.254±0.870[a]	3.208±0.412[a]	2.918±0.398[a]	0.046±0.024[a]	0.042±0.024[a]
-10	1162.79±0.289	2.768[b]±0.434	3.994±0.351	5.356±0.302[b]	0.129±0.044[b]	0.172±0.048[b]
-5	1190.48±0.577	2.157±0.581	4.167±0.402	4.686±0.426	0.107±0.048	0.120±0.049
0	1219.51±0.500	2.293±0.454	4.513±0.652	5.282±0.308	0.126±0.059	0.148±0.058
5	1251.56±0.289	2.480±0.804	6.688±0.685	6.722±0.718	0.208±0.064	0.209±0.066
27	1250.00±0.500	2.004±0.382	7.570±0.648	7.047±0.550	0.190±0.074	0.177±0.047
33	1234.57±0.577	1.905±0.457	9.230±0.413	8.823±0.465	0.217±0.023	0.208±0.031

[a] mean of three replicates with standard deviation. [b]critical point/departure from the observed trend

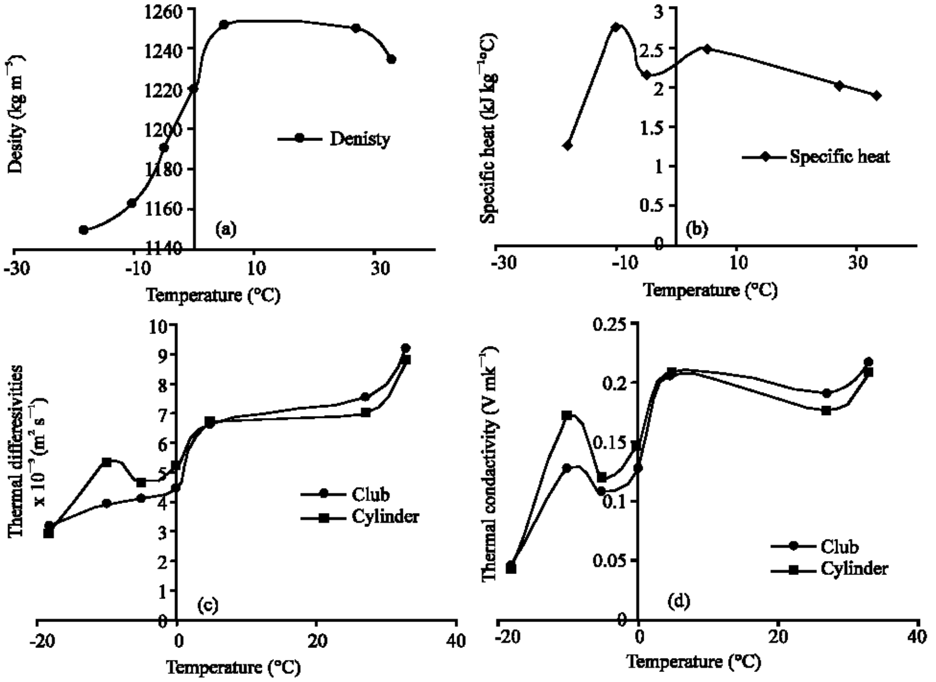

Fig. 1: Plots of a) density b) specific heat c) diffusitives d) conductivities of potato as functions of temperature

The experimental values of C_p as a function of temperature at constant moisture content of the sample as depicted in Fig. 1b was best explained by the following empirical equation:

$$C_{ps.potato} = 2492.678 - 3.428T - 2.400T^2 + 0.062T^3 \quad (5)$$
$$(R^2 = 0.66;\ S.E = 396.18)$$

Thermal diffusivity: As shown in Table 1 also, the mean values of the thermal diffusivity of sweet potato ranged from 3.208×10^{-8} to 9.203×10^{-8} m^2 s^{-1} and 2.918×10^{-8} to 8.823×10^{-8} m^2 s^{-1}, for slab and cylindrical geometries respectively. It was observed that the values obtained are less than 1.000 and they agree with thermal diffusivity values which were published for some other foods in literatures (Singh, 1982; Wallapapan *et al.*, 1984; Singh and Heldman, 1993; Rapusas and Driscoll, 1994; Nwanekezi and Ukagu, 1999).

Figure 1c depicts the thermal diffusivity, which increased with an increase in temperature below the initial freezing point. The plot of the experimental value of the thermal diffusivity of sweet potato (slab and cylindrical geometries) against temperature were best explained by the following empirical equations:

$$\alpha_{s.potato\,(slab)} = 5.086E-8 + 1.101E\text{-}9T + 8.494E-14T^2 + 4.613\,E-14T^3 \quad (6)$$
$$(R^2 = 0.93;\ S.E = 0.00)$$

$$\alpha_{s.potato(cylinder)} = 5.746E-8 + 5.106E-10T - 3.285E-11T^2 + 1.335E-12T^3 \quad (7)$$
$$(R^2 = 0.92;\ S.E = 0.00)$$

Thermal conductivity: Table 1 also shows the computed values for the thermal conductivity (λ) of the sample at various temperatures studied. The effect of changing state of the freezing front influences the thermal conductivity at a critical point of -10°C in both geometries of the sample after which there was a drop in thermal conductivity values as shown in the Table 1. It was also observed that geometry had only very little effect on these values and therefore, the three engineering properties are greatly influenced by their composition or constituents.

The effect of temperature variation on the thermal conductivity of this sample at constant moisture content are as shown in Fig. 1d and was best explained by the following empirical equations:

$$\lambda_{\text{s.potato(slab)}} = 0.153 + 0.004T - 9.756E\text{-}5T^2 + 1.104\,E\text{-}6T^3 \quad (8)$$
$$(R^2 = 0.84; \quad S.E = 0.03)$$

$$\lambda_{\text{s.potato(cylinder)}} = 0.172 + 0.002T - 0.000T^2 + 4.709E\text{-}\,6T^3 \quad (9)$$
$$(R^2 = 0.76; \quad S.E = 0.04)$$

It can be deduced that thermal conductivity increased with an increase in density for constant moisture content and, therefore, more mass of the sample was contained per unit volume. The greater the density of a sample, the lower the volume of air in the particle interstices. In addition, the greater the density, the greater the contact between particles, hence, higher thermal conductivity. Wallapapan and Sweat (1982) and Taiwo *et al.* (1995) also reported the same trend for defatted soy flour and ground and hydrated cowpea, respectively.

CONCLUSIONS

Some selected engineering properties of sweet potato of two geometries were measured at constant moisture level for different temperature levels. Temperature was varied between -18 and 33°C for two geometries: slab (measuring 3 cm×2 cm×1 cm) and cylindrical (measuring 3 cm in length and 1 cm in diameter).

The values of specific heat in this study were found to be high, running into thousands of joules per kilogramme for a unit change in temperature. This translates to the fact that a lot of energy is required to heat or cool sweet potato foods and that once tit is heated or cooled, it will retain its temperature for a long time. This is as a result of large moisture contents of the root and tuber crops.

The values of thermal conductivity and thermal diffusivity of sweet potato obtained in this study are low. This means that sweet potato is a poor conductor of heat. Heat energy diffusion or transfer during drying, refrigeration, freezing, thawing, evaporation, etc, are likely to be very slow. The low thermal diffusivities of the sample imply that they do not heat up or cool down rapidly. Going by the values obtained, therefore, movement or diffusion of heat energy from one point to another in sweet potato food is generally at very low rate when heat is being transferred. The variation of these engineering properties with temperature was best described by polynomials of the third order empirical equation.

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